LEAK DETECTION IN PIPELINES USING ENSEMBLE EMPIRICAL MODE DECOMPOSITION

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ABSTRACT

This thesis is discusses the techniques of leak detection in pipe system by using "*Ensemble Empirical Mode Decomposition*" method (EEMD). Effective leak detection is important to prevent leaks in pipes, particularly involving irrigation and drainage industry. Delay in detecting leaks can result an economic losses and environmental damage. In this study, water is used as the main medium and MDPE and GI was used. Wave propagation will be analyzed in the EEMD and the results of the analysis in the pipe with and without leakage will be compared. To detect the signal wave in the pipe, strain gauge pressure transducer and piezoelectric sensor was used. Transient signal that triggered by an automatic solenoid valve was used as a reference of the presence of a leak in the wave signal data in a particular period. The results of the analysis were successfully demonstrated by the presence of a leak in the pipe MDPE and GI in certain period and for a particular sample size. From the results, it can be concluded that the GI pipes is easier to analyzed compared to MDPE pipe. This is because the speed of wave in GI pipes is higher and had more superficial wave propagation.

ABSTRAK

Tesis ini membincangkan tentang teknik pengesanan kebocoran di dalam sistem paip dengan menggunakan kaedah "*Ensemble Empirical Mode Decomposition*" (EEMD). Pengesanan kebocoran secara berkesan amat penting bagi mencegah kebocoran di dalam paip terutamanya melibatkan industri pengairan dan saliran secara berkesan. Kelewatan dalam mengesan kebocoran mengakibatkan kerugian dari segi ekonomi dan kemusnahan alam sekitar. Dalam kajian ini, air dijadikan sebagai medium utama dan paip jenis MDPE dan GI digunakan. Sifat gelombang akan dianalisis di dalam EEMD dan hasil dari keputusan analisa di antara paip yang tiada dan ada kebocoran akan dibandingkan. Bagi mengesan isyarat gelombang di dalam paip, sensor tekanan dan sensor pizoelektrik telah digunakan. Isyarat yang dicetuskan oleh injap solenoid automatik telah dijadikan rujukan akan kehadiran kebocoran di dalam data isyarat gelombang dalam tempoh tertentu. Hasil dari keputusan analisis berjaya menunjukkan akan kehadiran kebocoran di dalam paip MDPE dan GI untuk saiz sample yang tertentu. Dari hasil kajian, dapat dirumuskan bahawa paip GI lebih mudah di analisis berbanding paip MDPE, ini kerana kelajuan gelombang di dalam paip GI lebih tinggi dan penyebaran gelombang lebih ketara.

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LIST OF SYMBOLS

ω	Wave dispersion
c	Phase speed
k	Constant
$a_{\mathrm{w}}\ (f)$	Water attenuation
s_{ℓ}	Leakage distance from stimulated transient
ΔT_{ℓ}	Time changes
$\partial_k(t)$	Amplitude modulations
$\psi_k(t)$	Oscillations
r_n	Residue data
c_j	Number of zero-crossing
ΔR	Resistance change
ϵ	Element (tensile and compressive strain)
a	Wave propagation speed
r_n	Residue data

LIST OF ABBREVIATIONS

EMD	Empirical mode decomposition
EEMD	Ensemble empirical mode decomposition
FT	Fourier transforms
FFT	Fast Fourier transform
GI	Galvanized iron
HDPE	High density polyethylene
HT	Hilbert-transform
HHT	Hilbert-Huang transform
IMF	Intrinsic mode function
MDPE	Medium density polyethylene
NASA	Noise assisted signal analysis
SCADA	Supervisory control and data acquisition system
STFT	Short Time Fourier Transform

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

A water resource is an important element in the contemporary society life now. From the end of the rural area, right down to the big city, each individual need clean water supply with best guaranteed quality. Currently, over 1.4 billion people live near water resources where the use of water already exceeds minimum recharge level resulting depletion of ground water (Human development report, 2006). History proves that every generation of human were always trying to produce the best and efficient water supply system. As time goes, every generation tries to improve the previous system and existing. Many intellectuals and engineers were trying to design and improve an efficient water and fluids distribution system.

The design must consider many aspects so that the system not suffer from leaks and rupture that may result huge loss of water of fluids and of course raising the cost of transferring Why they need to do improvement in the system?. This is because there is one major problem that occasionally happens in water distribution system that is leaking at the pipeline or water transporter. Nowadays, quick leakage detection and reduction is a high profile activity and seen by many water distribution company and the regulators as a priority, not only in the economical perspective, but also to preserve environment and natural resource from any waste and pollution.

1.2 RESEARCH OBJECTIVES

The objectives by do this research is to:

i. Identify the occurrence of leaks and know its exact location in the pipeline by using specific method which are Acoustic leak detection method and transient method.
ii. Utilize the signal processing technique in order to analyse leaking in the pipeline. With this, an EEMD method will be applied as the analysis method to collect and analyse the data.
iii. Observe and understand the behavioural of wave propagation in pipeline.

1.3 SCOPES OF RESEARCH

In order to achieve the above mentioned objective, the following scope has been drawn.

i. Design the experimental leakage detection test rig from MDPE and GI pipeline.
ii. Perform the experimental laboratory for the data measurement by using data acquisition device, strain gauge pressure transducer, piezoelectric sensor and DASY Lab software.
iii. Perform the signal analysis by using EEMD analysis technique.

1.4 PROBLEM STATEMENT

Pipe leaking can be happen in many forms such as burst, hole and cracks. In global world water loss or water leaking can vary between 10 to 40% of total water volume produced, which can be great economic importance (Gongtian et al).

In Malaysia, there had been recorded 21.90% of physical and 14.70% of commercial water loses in year 2009. From Figure 1.1, Pahang have the highest percentage water loses that is 59.9% followed by Sabah (49.41%), N. Sembilan (49.16%), Kelantan (48%), Kedah (44.97%), and Perlis (44.67%). The other states also have high percentage that is exceed 20% of loses (Salleh et al, 2010).Leakage of water usually occurs from mains and service connections at joints and fittings. The leaking occurrence can't be taken lightly because it may cause great loses in economy and environment.

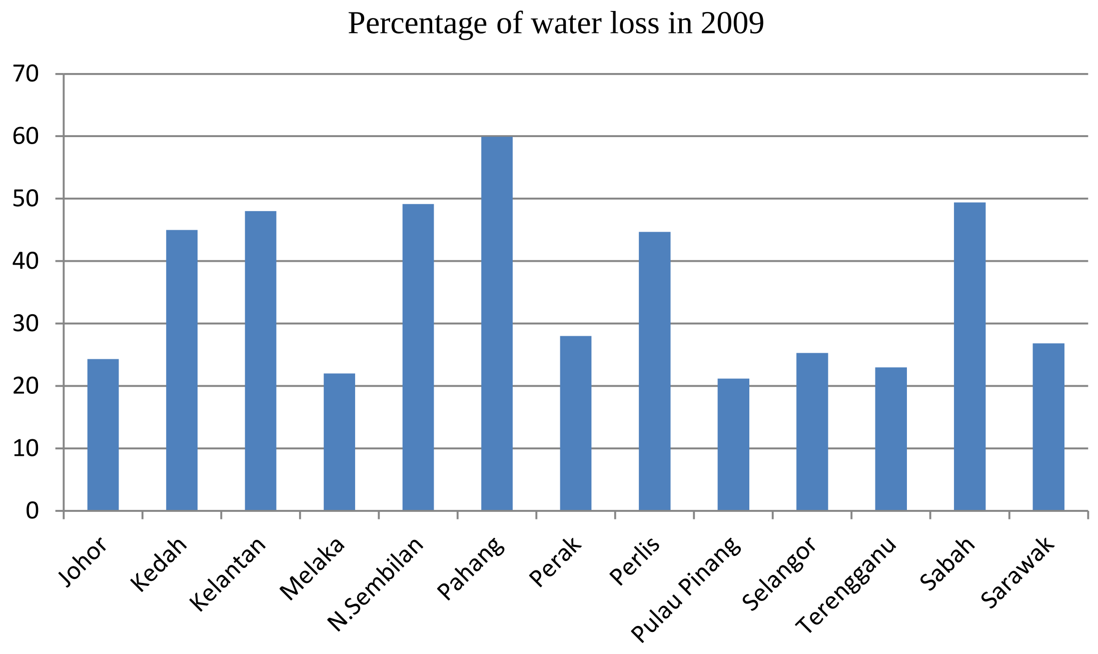


Figure 1.1: Percentage graph for water loss in each state in year 2009

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter there will be discuss about several leakage detection techniques in pipeline and what analysis method that will be implies in order to obtain an accurate and acceptable result. In this chapter also, there will be have general knowledge about wave propagation and wave’s behaviour in pipelines. This will includes steel and MDPE based material pipes and the effect of waves to the features that used in pipelines. For Leakage detection technique, there have two types which are external and internal based technique or otherwise known as hardware and software techniques (Geiger et al, 2003). External bases technique is a system that utilizes any field instrumentation to monitor and check around external pipeline parameters while the internal based technique is a system that monitors internal pipeline parameters. The wave’s propagation and how to do currently exist analysis method after do the test also will be described and explained detailed in this chapter.

2.2 LEAKAGE DETECTION TECHNIQUE

2.2.1 Acoustic leak detection

Acoustic equipment is commonly method that used to locate leaks in water distribution pipes. These techniques usually include simple listening devices, leak-noise correlators and noise loggers or collectors (Hunaidi, 2005). This technique can be divided into two methods which are manual handling acoustic method and the other one is acoustic with correlator method. The manual handling acoustic leak detection use listening devices such as ground microphones. The devices is use to pinpoint leaks underground and needs on the experience of the user.

Compare to acoustic with correlator method, the manual handling method is time consuming and the accurate of results can be questionable. An Acoustic with correlator method is more efficient and yield more accurate results (Hunaidi, 2005). The method may be more accurate able in obtain the result due to extensive training of the users. For acoustic with correlators method, there will have two sensor placed on the opposite sides of the leak input sound spectrum to a computer and the data which is noise will be captured and analysed (Newfoundland, 2006). Figure 2.1 shows acoustic method diagram.

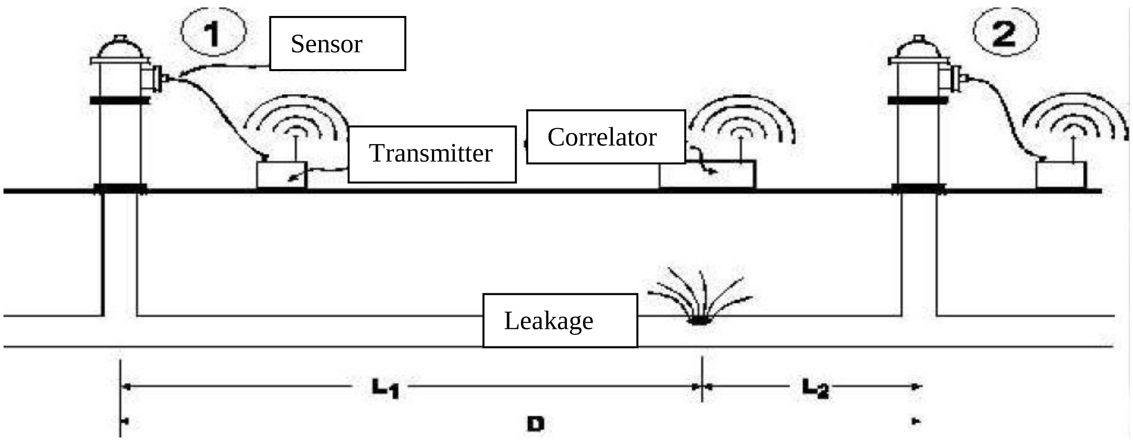


Figure 2.1: Acoustic with correlator method and equipment

(Source: Newfoundland, 2006)

The drawback of this method is, it can be unreliable when the test be done in plastic and large-diameter pipes. This happen due to noise does not propagate long distances in plastic pipes. It propagates at much slower speed that in a corresponding metal pipes (Brennan, 2007). Another drawback is the result may inconsistency when survey had been done at frozen ground. This is because the noise is too quiet to be detected and captured by sensors. The acoustic with correlation method is bracketed the leak with two sensors.

2.2.2 Visual observation method

Visual observation method is simple simplest method to detect leaks. The observation or test must be done by an experienced user to detect the exact location and leaks occur. The detection method includes searching any irregular patterns near the pipeline or can listen if there any weird noise produced from the pipelines. This method totally depends on how the user conducts the test. The accuracy of this technique will rising if the user or the operator has more experiences. Besides that, size of leak, material of pipeline also contributed in order to obtain good result.

2.2.3 Vapour-monitoring method

This detecting method identify leak by placing a sensor parallel to the pipeline. Leak will be found when the hydrocarbon vapours will diffuse into the sensor tube and sensor will be pumped to base station. The location of leak can be located by arrival time at detector against with arrival time of gas injected in sensor tube. The advantage of this method is it can detect even small leaks, that can’t be detected by any conventional leak detection method that based on pressure and flow balance. Drawbacks of this specified method is its slow response time for detection. The time of response is depending at the pumping rate through pumping rate. Figure 2.2 shows leak detection by vapour monitoring system.

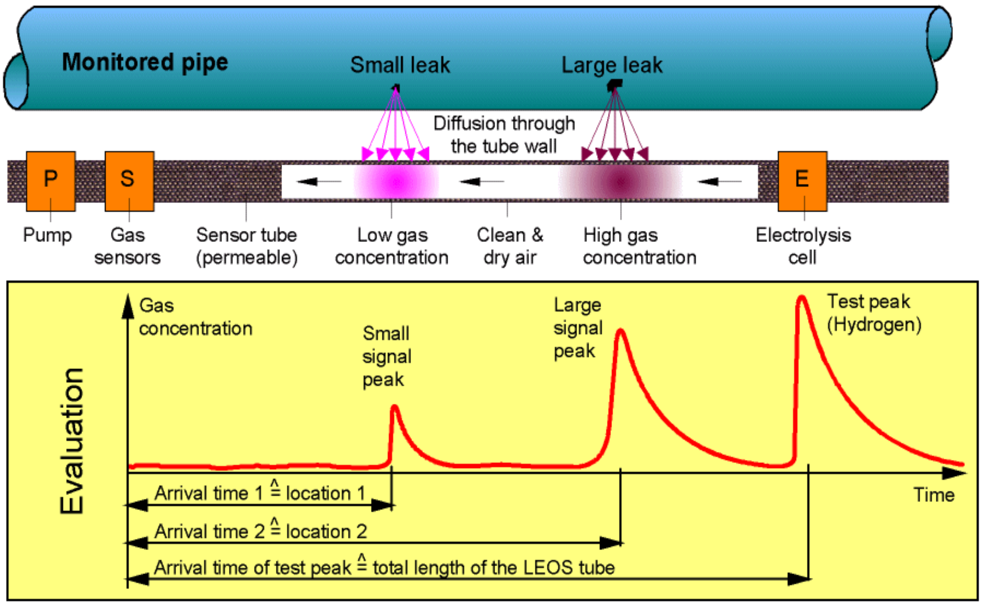


Figure 2.2: Leak detection by vapour monitoring system

(Source: Brennan, 2007)

2.2.4 Liquid sensing method

Liquid sensing method is typically called as self-contained leak detection and location system. Usually , liquid sensing cable are buried near to pipeline and design specifically to reflect any changes in transmitted energy pulses. The pulses will continuously send by microprocessor through cable and then reflected back to microprocessor. When leak occur, the cable will be saturated with the fluid, and it will alter the impedance of sensing cable and turn reflection pattern return to microprocessor (Alaska department of environmental conservation, 1999). This will cause leak alarm at the location of the altered impedance. This method provides high accuracy result in determining leak location and easy software usage and maintenance. For this method, the drawback is it has an expensive installation cost.

2.2.5 Mass-balance method

Mass-balance method is a technique that relying on the principle of conservation mass. The technique is relatively identifying leak when less of fluid leaves the pipe than expected measurement of inlet flow and estimate of fluid shouldfill in the pipe (Stafford et al, 1996). The method also known as supervisory control and data acquisition system (SCADA). Mass-balance method is quite similar with volume balance method where both of method relying on principle of conservation of mass. The difference in mass of both ends of pipes must be balance against change of mass change in the pipeline (www.pcb.com). The general formulations for mass-balance method are:

$$\Delta Mi - \Delta Mo = \Delta Mpipe$$

(2.1)

Where:

ΔMi is mass entering pipeline

ΔMo is mass exiting pipeline

$\Delta Mpipe$ is change of mass in pipeline

If the leaks are occur, the mass in the pipeline is imbalance. The equation for the leaking is:

$$\Delta Mleak = \Delta Mi - \Delta Mo - \Delta Mpipe$$

(2.2)

In order to obtain leakage in the pipeline, the difference of amount mass at the inlet pipes is calculated with the excess mass of fluid at the other side of pipes and change of mass. For this method the accuracy of estimated pipe contents in depend to sensitivity of mass-balance calculated, therefore this method is dependent upon accuracy of pipeline instrumentation (L. Scott et al, 2003). The method may detect small leaks in steady state conditions and can be more accurate at long period time of fluid flow at the inlet and outlet of pipe.

2.2.6 Statistical analysis model

Statistical analysis method is one way of software method detecting leakage in pipeline without using mathematical model but by using statistical of analysis.

This method is performed by measured pressure and flow at varies location along the pipeline. A leak alarm will be generated if the system encounters relative changes in the parameters (pressure and flow of fluid) (Zhang, 1993). After parameter is analysed at different operating states, the leak point are to be set in order to check the absence of leaks. The leak can't be detected until it grows beyond the leak point. The method also can estimate leak location and this method is robust also easy to adapt to different pipeline configurations (Pal-Stefan Murva, 2008). One of drawback of the method is, it has high cost. Figure 2.3 shows result after analysed by statistical analysis method.

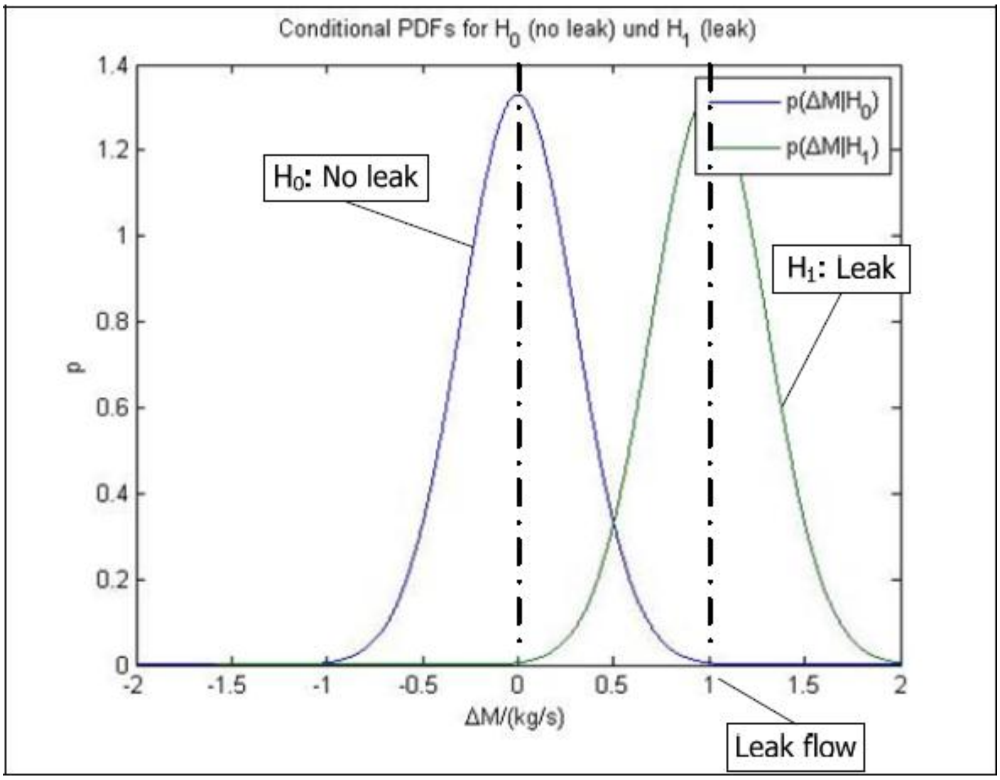


Figure 2.3: Probability density functions for leak and no leak condition (Source: Pal-Stefan Murva, 2008)

2.2.7 Pressure point analysis

Pressure point analysis is principle that recorded series of pressure measurement taken at the pipeline before and after leakage occur (Farmer, 1991). The method used to compare the current pressure signals in the pipeline. The data collected and the data trend will be compared in order to locate leakage in the pipeline. As the leaks occur, pressure will drop by amount Δp and this data will be compared against lower limit after steady state conditions. Leak alarm will increase as pressure drop below the lower limit (L. Scott et al, 2003). In 1989, pressure point analysis method had been patented. The method can detects leaks from holes as small as 1.6 mm and leaks rates less than 0.1% of flow within seconds. Figure 2.4 shows pressure point analysis system.

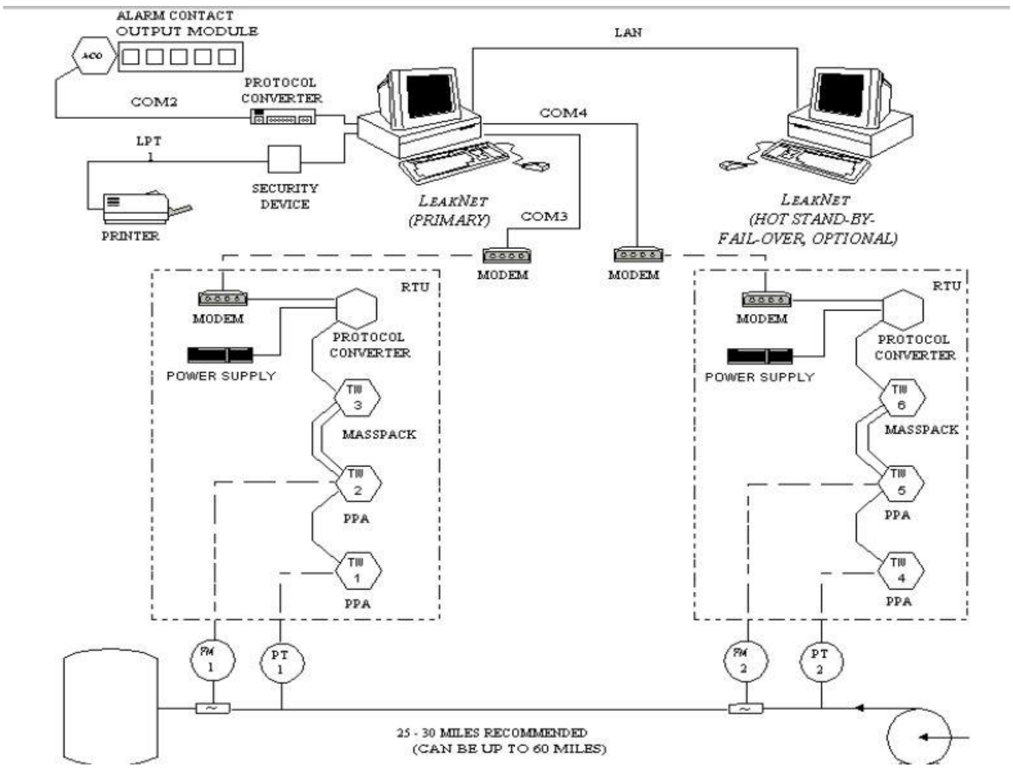


Figure 2.4: Leak detection by pressure analysis

(Source: L. Scott et al, 2003)

2.2.8 Transient-based method

This method used to rising the leak location sensitivity by simulating and reproducing transient in the pipeline so that leak effect can be spread out and captured (Stafford et al, 1996). Transient based method needs complete mechanical characteristic description of the pipeline and certain mathematical model to study the actual pipeline conditions at specific flow meter points. For transient-based method, it can be influences by any changes in the physical structure of the pipeline such as junction, blockage and expansion. Propagation of waves in pipeline also gives effect in transient signal. In transient method, leakage can be detected typically via comparison of the pressure signal that captured by monitoring devices to the signal that would be observed if the system that did not have leak. The other way is where leakage can be detected isthrough its role in pressure relief.

When the high pressure passes, leak will causes some attenuation in first transient signal by let some of fluid down with pressure escaped. In transient-based method, both types of waves propagation (dispersion and attenuation) is play important roles to detect leakage. Figure 2.5 and Figure 2.6 shows propagation of transient generated from source and after leak discovered.

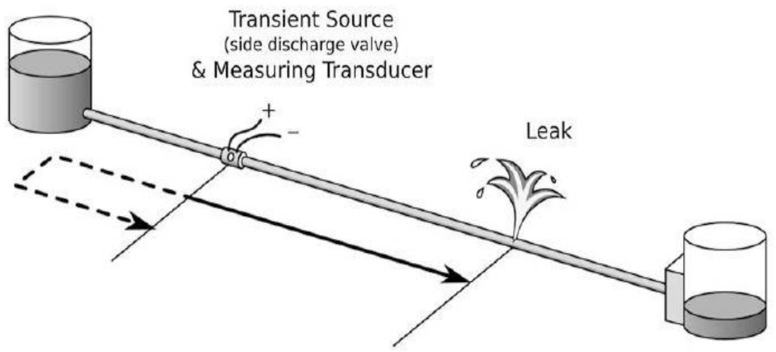


Figure 2.5: Transient propagation-waves generated from source
(Source: Stafford et al, 1996)

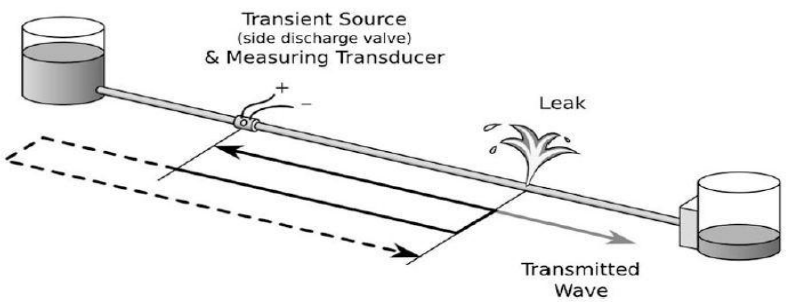


Figure 2.6: Transient propagation-leak reflected
(Source: Stafford et al, 1996)

2.3 WAVES PROPAGATION

Wave propagation is waves spread movement along the container (pipeline). By using the propagation of wave, signal that response along the pipe can be captured due to change of impedance in pipe (Cheng, 2012). From this behaviour, leakage or any disturbances that occur in the pipeline can be detected efficiently. In waves propagation there have behaviour traits such as wave dispersion, wave's attenuation, and water hammer phenomena.

2.3.1 Waves dispersion

Dispersion is a phenomenon of waves speed change with frequency due to structure and geometric of pipeline (Gongtian et al). This traits activity makes the elastic wave signal in starting point distorted with the transmission process. The general dispersion relation for frequency can be written:

$$\omega = \omega(k) \tag{2.3}$$

and for the phase speed is:

$$c = \omega(k)/k \tag{2.4}$$

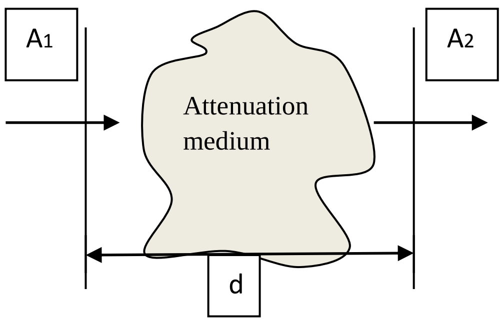
where:
c is phase speed
ω is wave dispersion
k is constant

This equation is implies disturbances and propagates without any change of shape. The dispersion waves is depending to wave energy that emit along in the container which is pipes. If the energy of wave that emit in the pipes is lower, the dispersion waves is spreads out. This will explain that dispersion of waves in steel based pipeline is strong compare to PVC or plastic based pipeline.

2.3.2 Waves attenuation

Wave attenuation is an elastic wave propagation that has increased distance, energy and lower amplitude of vibration. This wave behaviour mainly contains dispersion, scattering and absorption traits (Gongtian et al). Attenuation also known as wave dissipation produces an effect which further weakens the waves. This further weakening results from scattering and absorption. Attenuation is affected by many types of variable so that it's not possible to give generic values that are useful for quantitative analysis.

Attenuation principle and formulation are:



$$A_2/A_1 = \exp\left[- a\,(f)\, d\,\right] \tag{2.5}$$

Where:

$a\,(f)$ is attenuation

A_i is plane area

d is distance between two surface area

Attenuation for water is:

$$a_w\,(f) = 25.3 \times 10^{-15}\, f^{\,2}\ \mathrm{N}p\,/\,m \tag{2.6}$$

For high attenuation, wave speed as well as amplitude is affected. As waves travel and encounter blockage, feature and leakage, the waves will transmit. If the transmitted wave is greater, the attenuation wave will drop or less.